# Inaccuracies of HS2 noise calculations and model

## Summary

This paper presents an analysis of the HS2 noise calculation model which shows that there are four significant errors in the methods for calculation of predicted noise carried out by contractors, as prescribed by HS2 and presented in noise demonstration reports. These errors represent a 8.5dB under-prediction of night-time $L_{Amax}$ noise in excess of LOAEL affecting Wendover.

1. **The HS2 noise model underestimates far field noise level $L_{Amax}$ by 2dB**

   Analysis of the data provided by HS2 shows that at far field noise levels below 71dB the HS2 noise model underestimates $L_{Amax}$ (maximum noise) by 2dB and this result is statistically significant. The error also applies to $L_{Aeq}$.

2. **The LOAEL for $L_{Amax}$ at night incorrectly calculated for any nightly event as a result of the spread of $L_{Amax}$ values**

   Night-time maximum noise ($L_{Amax}$) will be in excess of LOAEL according to its official definition if any (a single) noise event exceeds 60dB. In the current methodology used by HS2, the threshold of 60dB is applied to the average of noise events, which is a different and lower indicator.

   To account for and accommodate the variation in the noise level of individual train passby events, in order to meet the official definition of LOAEL, average noise level needs to be at least 5dB quieter than the average noise level figures which HS2 are using.

3. **400m trains not appropriately considered or modelled**

   The HS2 model treats 400m trains as two separate 200m trains. However, a 400m train will be noisier than a 200m train and so $L_{Amax}$ should represent the noise of a 400m train. We have made an estimate of the additional noise, for example at 800m over flat ground this would be an additional 1.5dB.

4. **Pantograph noise ignored**

   The HS2 method for calculation of $L_{Amax}$ normally drops the pantograph noise from the calculation, which while correct at short distances, is not correct at (say) 800m. The effect is small however and we have not added a further adjustment term for this.

5. **$L_{Aeq}$ incorrectly calculated**

   The variation in the noise level of individual train passby events also affects the calculation of $L_{Aeq}$ (the HS2 measure of average noise) and due to the scale of the range of values their calculated figures should be uplifted by 1dB.

## Conclusion

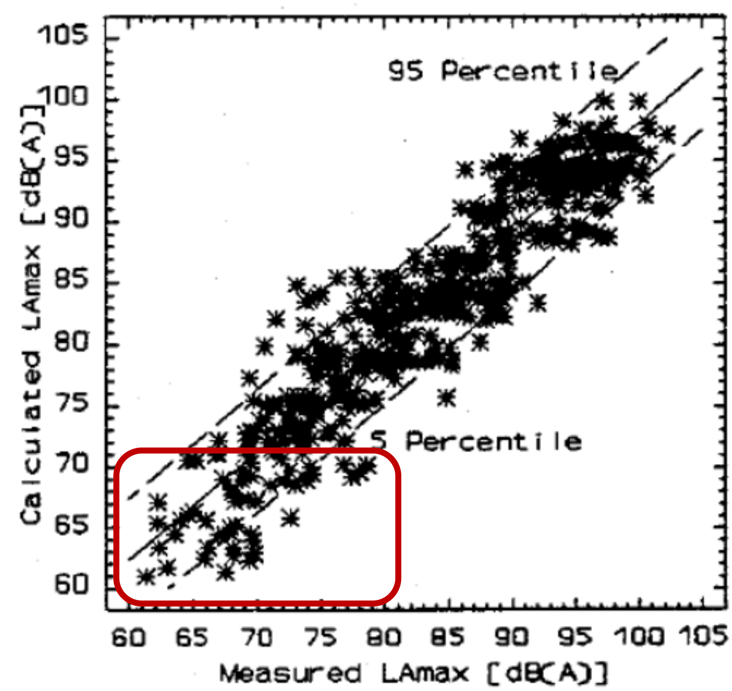
The combined effect of the errors in the calculation of $L_{Amax}$ is an additional 8.5dB in the far field, which covers a large section of Wendover. These factors are reasonably foreseeable within the design and construction stages, and should be taken into full account by the contractors undertaking the design, construction and planning of the railway and by Planning Authorities reviewing noise demonstration reports.

U&A 1026 requires the use of noise prediction models valid for the range of circumstances over which they are applied. The HS2 noise prediction model would not be valid in this range without the corrections above. U&A 1025 requires predictions to be made in all reasonably foreseeable circumstances, including prediction model uncertainty. Both of these are repeated in Planning Forum Note 14 (PFN 14).

Any noise demonstration report which predicts $L_{Amax}$ below 71dB should therefore either adjust the predictions or include a section on prediction model uncertainty which spells out the errors in the noise model in this range and quantifies the effects on all affected receptors.

## 1. The HS2 noise model underestimates $L_{Amax}$ far field levels by 2dB

The London-West Midlands Environmental Statement[1] (The ES) includes the following graph for the measurements which were made to evaluate the HS2 noise model. This taken from an Ashdown Environmental Limited paper[2] (The AEL Paper).

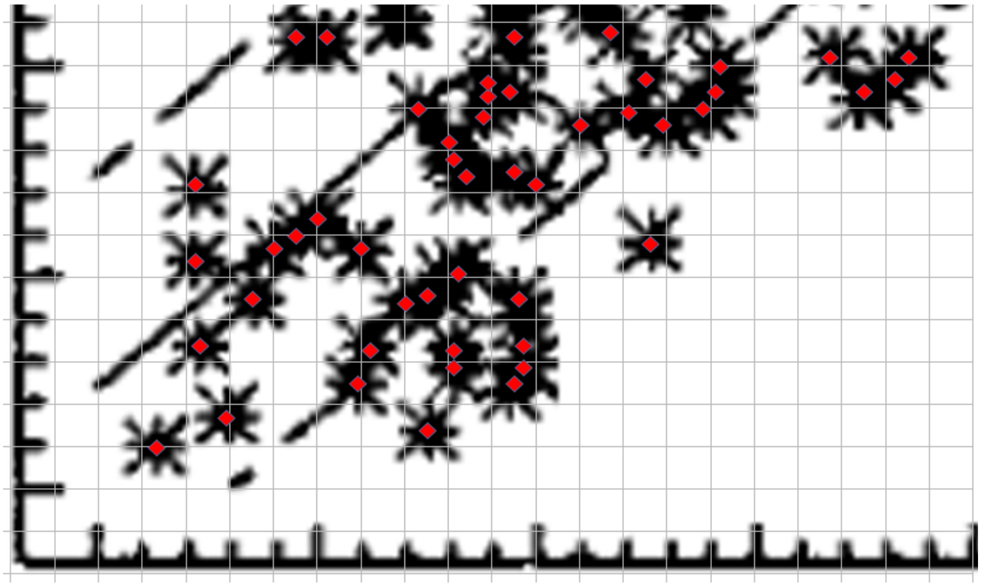



Wendover HS2 had observed that in the highlighted area (below 71dB calculated), the observed figures appeared to be higher than calculated. This is the range which affects almost all receptors in Wendover which are above night-time LAmax LOAEL. The data represented by the points on this chart within the red box were extracted to a table (see Appendix A). There were 48 data points which provides a sufficiently large sample for this analysis.

To verify that this has been done with sufficient accuracy, a scatter chart was superimposed on the original HS2 chart, to position the points in the centre of the stars on the original, as shown below:

[1] November 2013 Volume 5 | Technical Appendices Methodology, assumptions and assessment (route-wide) (SV-001-000) Sound, noise and vibration, Annex D2, page 24

[2] Validation of the AEL Methodology for the Calculation of Train Noise, Williams PR, Hood RA, Collins KM and Greer RJ.



The mean difference between measured and calculated values was 2.06 dB. To assess the significance of this it is necessary to look at the standard error of the mean difference. The standard error of the model is 3dB but this relates to a single observation rather than a group of observations. The standard error of the mean is obtained by dividing this by √(48-1) giving 0.44. Based on this, the probability that the true mean difference is zero or less is 0.00013%, which is vanishingly small.

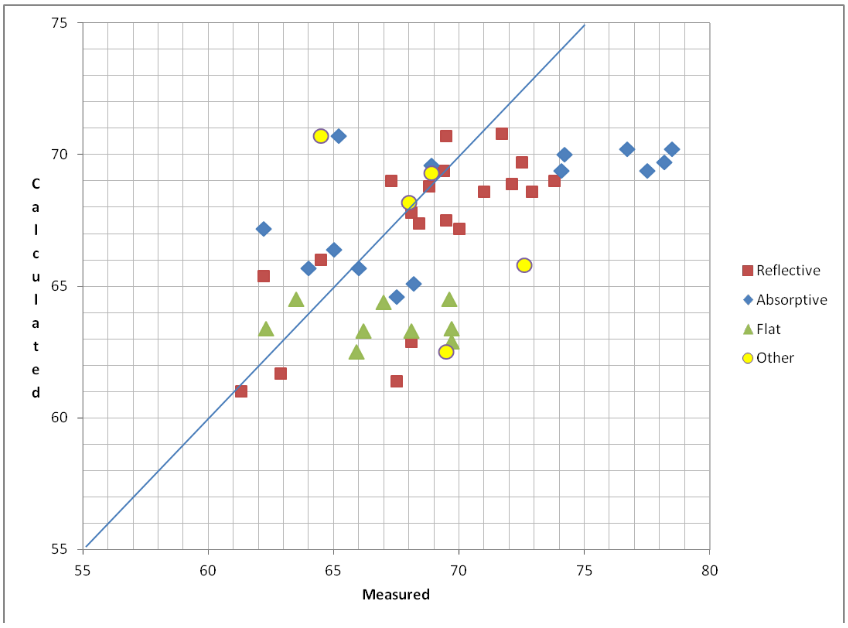
Since we have two sets of values (measured and calculated) for the same set of data points, it is also possible to use a paired t-test to determine the probability that the difference between the two sets is as a result of chance. This does not rely on the standard error of the model, but only uses the data itself. The result of this (two-tail test) is a probability of 0.029% that the difference between the two data sets is caused by chance. In other words, we can be 99.97% certain that there is a significant difference between the measured and calculated data sets.

The conclusion from this is that the HS2 noise model is not valid in this data range below 71dB. It can be corrected by the addition of a 2dB adjustment.

Actual measurements are of course still subject to standard error around the adjusted prediction. Having made the 2dB adjustment to the results, the standard deviation of the difference is 3.6 dB, so the actual observed noise will still vary either side of the prediction.

It is also worth noting that the correlation coefficient between measured and calculated is 0.5, which is low. This means that only half the variation in measured noise between individual data points is explained by the noise model, and the remaining half is as a result of unidentified factors.

The AEL Paper also contains separate graphs for flat ground, reflective barriers and absorptive barriers, from which it is possible to identify most of the data points, as shown on the following chart:

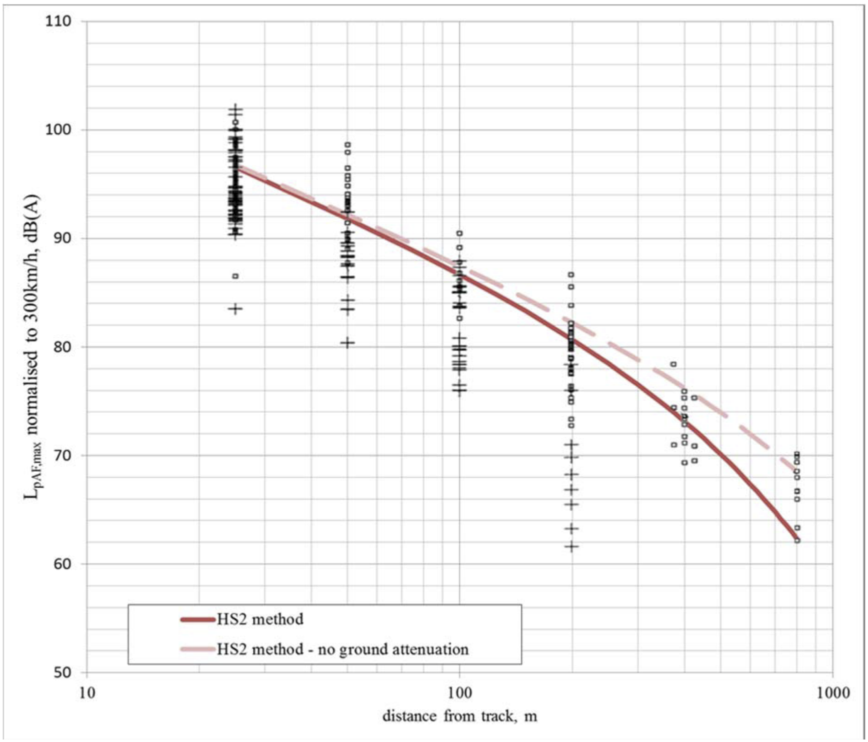



From this it is possible to calculate the model error (mean difference between measured and calculated) for each type of data point:

| Type | No of Points | Mean Difference |
|---|---|---|
| Flat Ground | 9 | 3.3 |
| Absorptive Barriers | 14 | 2.3 |
| Reflective Barriers | 20 | 1.5 |

However the sample sizes are now small, and a t-test shows that the difference between the results for the three types of data is not statistically significant. Hence the conclusion is that the model error applies to all three situations, and a single correction value should be used in all cases.

The ES also provide charts representing data from a measurement campaign carried out in 1989 – 1990 on the TGV Atlantique route in France. TGV-A high speed trains were running at nominal speeds of 300kph on flat ground. Annex D2 Figure 18 is shown below:



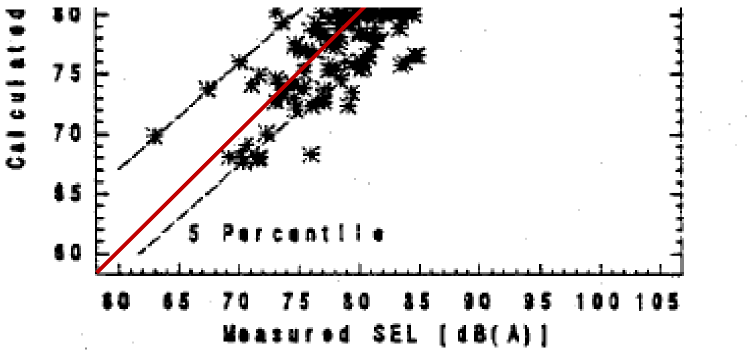

The rectangles represent downwind conditions and the crosses upwind conditions. The lower line represents the HS2 model, which is valid for downwind conditions. It will be seen that for the lowest group of points (800m), in the range up to 70dB, the measured results are consistently above the calculated results and the average difference is 2.5dB. This set of data would therefore confirm the finding from the AEL Paper that there is a consistent error of around this magnitude.

HS2 have suggested there is additional data on noise measurements of HS1 trains taken in 2011 by Arup which indicate actual noise levels are lower, though this data does not appear to be in the public domain. If this data could be made available we would of course review our conclusions.

In summary, observed results in this range can be expected to be typically equal to:

**Observed = Calculated +2dB ±3.6dB**

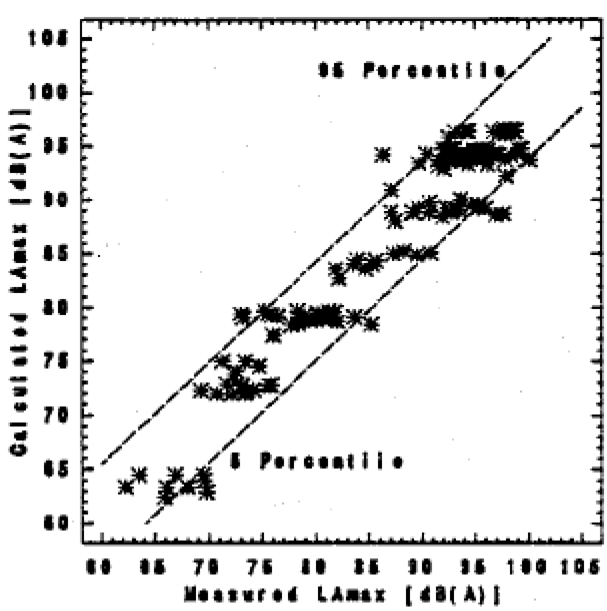
The AEL paper also includes a graph of measured against calculated for SEL, from which it is clear that the same error will apply to SEL (in this case up to 75db) and hence $L_{Aeq}$, as shown in the section given below.



## 2. The LOAEL for $L_{Amax}$ at night incorrectly calculated for any nightly event as a result of the spread of $L_{Amax}$ values

Variation will be observed by a single receptor of the noise generated by individual passby events. It is clear that in the graphs shown in both the ES and the AEL paper, the individual points represent individual passby events. The reasons for this are:

- If any preliminary grouping of data had taken place, one would expect this to have been mentioned as part of the description of the methodology. The process would have required some manipulation of the data, as the speeds of individual trains would have varied, and it would be unusual to have grouped data in this way without mentioning it.
- The data in the AEL paper and shown in the graph reproduced above was used in a multiple regression analysis. It would be most unusual for this not to be done on the actual observed data points.
- It is clear from the description in the ES relating to the TGV data that each point represents an individual passby, and the ES comments that "at a given distance from the track, the measured data is characterized by a large spread" which is evident from the chart.
- The AEL Paper has a corresponding graph representing flat ground:




Although the axes are reversed, the distribution is similar to the TGV chart, and as with the TGV chart shows six clusters of data. The vertical axis shows calculated rather than distance, but as this is the flat ground model, distance is the only independent variable in the HS2 model and so one can conclude that as with the TGV data, each cluster represents individual observations at a given distance. Again a similar wide spread of measured results is observed (only the downwind observations are shown here).

Hence, it is reasonable to conclude that the **standard deviation of the noise from individual passby events** in downwind conditions is close to the **model standard error of ±3dB**.

Both reports speculate about the reasons for the variation in individual train passby events. The AEL paper says "*The residual errors ... are attributable to a number of sources. It is well known that meteorological effects have an increasingly significant influence on the propagation of noise with increasing distance. Other factors such as trackside were also found to be significant together with large variations in source terms*". The ES discusses the effect of wind speed and temperature gradients and adds "*the spread around the predictions can be partly attributed to variations in the sound emission* *levels across trains and measurement sites*". Although there is mention of the need for more work in this area, WHS2 have not found any evidence that this work has been done.

Therefore, the "standard error" allowance in the ES is consumed by pass-by variation, independently of any modelling error (such as in Section 1 above) in the prediction for any specific receptor.

If there is new evidence suggesting a different degree of variation in passby noise, for example based on measurements undertaken on Spanish trains we would welcome sight of this to take it into account.

Information Paper E20[3] in Appendix B Table 1 provides the following definition of LOAEL for $L_{Amax}$ at night:

| Time of day | Lowest Observed Adverse Effect Level (dB) | Significant Observed Adverse Effect Level (dB) |
|---|---|---|
| Day (0700 – 2300) | 50 $L_{pAeq, 16hr}$ | 65 $L_{pAeq, 16hr}$ |
| Night (2300 – 0700) | 40 $L_{pAeq, 8hr}$ | 55 $L_{pAeq, 8hr}$ |
| Night (2300 – 0700) | 60 $L_{pAFMax}$ (at the façade, from any nightly noise event) | 80 $L_{pAFMax}$ (at the façade, from more than 20 nightly train passbys), or 85 $L_{pAFMax}$ (at the façade, from 20 or fewer nightly train passbys) |

Information Paper E20; Appendix B; Table 1 - Noise effect levels for permanent residential buildings

It is evident from noise demonstration reports and from discussions with HS2 that this is currently being assessed by comparing the output from the HS2 noise model with 60dB. This output represents the average, or expected value of $L_{Amax}$. HS2 have explained that the reasons for this approach are:

- It represents the impact on the community.
- It is the approach which has been used consistently in all noise figures presented.
- It is consistent with how it is done on other projects.

However it is apparent that this approach is not consistent with the wording in E20, from which it is clear that to avoid breaching LOAEL, **every nightly noise event must be quieter than 60dB**. From the analysis above of the variation in the noise of passby events, even if the average is within 60dB, many individual passby events will be louder than 60dB.

It is also evident that the wording in E20 is fully intended. Information paper E20 is dated February 2017. However in the discussions of the Acoustic Review Group (2012-2014) there are several references to the relationship between the value of LOAEL and the frequency with which it exceeded. For example in one discussion on the possible use of 60dB, the following text appears "ARG noted that to trigger the identification of noise exposure category C under the (now disapplied) PPG 24 criterion had to be exceeded several times per night. There was a recent legal case which suggested that several amounts to 2 x per night".

[3] E20: Control Of Airborne Noise From Altered Roads And The Operational Railway.

The wording in E20 has evolved to what is there now. The HS2 change log records for 16/07/2015 the following change to E20 "In Appendix B, Table 1 Insertion of times of day and *'(at the façade, from any nightly noise event)*' in Column 2 and *'80 $L_{pAFMax}$ (at the façade, from more than 20 nightly train passbys), or 85 $L_{pAFMax}$ (at the façade, from 20 or fewer nightly train passbys)*' in Column 3".

On 8/07/2014 Mr Rupert Thornely-Taylor, expert witness, gave a presentation to the HS2 Select Committee on noise, in which he covered this point. He noted "*The lowest observed adverse effect level has a value of 60 $L_{pAFmax}$ at the facade. The significant observed adverse effect level is 80. The figure is different according to the number of trains..."* and commented *"the thresholds of LOAEL are really quite low*, *generously low*".

He also explained the detailed process which had gone into the formulation of the wording, and it's authority: "*I will show the way that HS2 has approached the application of LOAEL and SOAEL to the application policy. It has done that through a long process which has included review by a body called the Acoustic Review Group, which included not only members of the HS2 project but Government officials. The LOAEL and SOAEL application also is to be found in the Environmental Statement which, of course, is signed off by the Secretary of State for Transport after he consulted the relevant Departments and officials. The application of LOAEL and SOAEL and the numbers attached to them that are in the published Information Papers are, effectively, the Government's interpretation of its policy, having been signed off in that way.*"

He gave a further presentation to the House of Lords High Speed Rail Bill Committee considering HS2 Phase 2 on 20/07/2020, in which he again referred to this LOAEL limit: "*the LOAEL for the maximum sound level due to the passage of a train at night is 60 dB outside the façade – that's from any event – and the SOAEL is two numbers, depending on the number of train movements that occur during the night*".

It is therefore clear from the above that the wording of E20 has been carefully considered, signed off, and means exactly what it appears to mean – LOAEL will be exceeded if any (a single) nightly noise event exceeds 60dB.

Based on the "HS2 July 2017 Strategic Case annex" it appears that there will be 49 night-time train movements at Wendover. With a normal distribution with a standard deviation of 3dB, the following table illustrates the number of train movements which would exceed 60dB on a typical night in downwind conditions.

| **Average $L_{Amax}$** | **No of Trains** |
|---|---|
| 60 | 25 |
| 58 | 18 |
| 58 | 12 |
| 57 | 8 |
| 56 | 5 |
| 55 | 2 |
| 54 | 1 |

It is therefore evident from the above, that **noise demonstration reports should be using a noise level of no more than 55dB** (output from the noise model) in order to assess the number of receptors which exceed LOAEL.

## 3. 400m trains not appropriately considered or modelled

The existing HS2 modelling treats 400m trains as two separate 200m trains. This does not take into account the fact that a 400m train will be noisier than a 200m train. As discussed above, when considering $L_{Amax}$ from multiple train pass-by events, it is the loudest events which must be used. So the $L_{Amax}$ should represent the noise of a 400m train.

The HS2 noise model for $L_{Amax}$ considers only the louder of body aerodynamic noise (from the front of the train) and pantograph noise (from the rear of the train). In most cases body aerodynamic noise will be louder, in which case the $L_{Amax}$ is assumed to occur when the front of the train passes the observation point.

We could therefore estimate the additional noise from a 400m train by assuming it consists of two 200m trains one immediately behind the other; the second train will have no body aerodynamic noise, as this only occurs once, but the rolling and startup/power noise will be as a normal train.

As an example, the HS2 model for a Classic Compatible 200m train on flat ground (no barriers) at a distance of 800m assuming a speed of 330kph and a receptor height of 4m produces a $L_{Amax}$ of 61.2dB.

If one adds a second 200m train immediately behind with zero body aerodynamic noise, the distance to the front of this train is now 825m and the HS2 model calculates that the $L_{Amax}$ is 57.2dB.

At 800m the difference in position of noise sources will have little effect, so all noise sources will be combined to give the $L_{Amax}$. So adding these using the normal dB addition formula, the combined noise is therefore 62.7dB so an **increase of 1.5dB compared with a single 200m train**. $L_{Amax}$ should therefore be increased by 1.5dB in this example to accommodate the running of 400m trains.

## 4. Pantograph noise ignored

The HS2 calculation method for $L_{pAF,max}$ includes the larger of body aerodynamic and pantograph noise. The ES justifies this as follows "*This equation is based on the assumption that the pantograph and pantograph recess are not on the leading and trailing coaches, and hence the $L_{pAF,max}$, body aero, which normally occurs at the front of the train (nose and leading bogie) does not occur at the same time as $L_{pAF,max}$, pantograph which is robust for modern distributed power trains*". In practice this results in the pantograph noise being dropped in most situations.

While this may be true at short distances from the train, once the distance increases all points on the train are at approximately the same distance from the observation point. For example for a 200m train where the front of the train is 800m from the observer, the rear of the train is at 825m. In this situation all noise sources contribute to the maximum noise, so the HS2 model is underestimating noise.

Our estimation in the presence of a barrier is that the effect is small (around 0.5dB) so we have not included a further adjustment for this.

## 5. $L_{Aeq}$ incorrectly calculated

The variation of train noise events also affects the calculation of $L_{Aeq}$. In his presentation on 20/07/2020 (see section 3 above) Mr Thornely-Taylor, expert witness, explained this point "*it's not actually an average of sound levels. It's an index and the important thing is that the way it's calculated gives very strong weightings to the high noise events that occur during a period. It's **not the same number that you'd get if you wrote down the sound level every minute throughout the day and average all those numbers**. If there were one or two noisy events during the day and you calculated the $L_{Aeq}$ for that period you'd get a much higher answer, a numerically greater answer, than you would if you did that sort of averaging.*"

But the incorrect method for calculating $L_{Aeq}$ described by Mr Thornely-Taylor above (in bold-italics) is exactly the method that is employed by HS2.  Unadjusted numbers from the noise model are being used, so effectively the average dB level of all train movements. Based on an average of 60dB and a standard deviation of 3dB, it is possible to estimate the correction which needs to be made to the calculated $L_{Aeq}$, which **requires an addition of 1dB to the calculated figures**. HS2 calculations should therefore adjust all $L_{Aeq}$ figures by the addition of 1dB.

## 6. Conclusions

The railway noise prediction model used by HS2 has a number of significant limitations and inaccuracies which need to be accounted for during the planning and construction stages of the railway.

Taking the inaccuracies described in this paper, the HS2 has a far field under-prediction error of 3.5dB ± 3.6dB. Additionally, for achieving the target noise level LOAEL HS2 is using incorrect methodology for calculating $L_{Amax}$ resulting in an under reporting error of 5dB. Combining these two errors together there are systemic errors in HS2's noise management methods resulting in **8.5dB additional noise in excess of LOAEL** in the far field, which covers a large section of Wendover**.**

The evidenced limitations and inaccuracy of the HS2 noise model for far field low level noise propagation against measured data set must be considered by the undertaker during design and planning of the railway under their legal obligations.

U&A 1026 states: "*The Secretary of State will require the nominated undertaker to use noise or vibration prediction models during the design and construction phases of the Proposed Scheme that are validated for the range of circumstances over which they are applied*". Evidently, the noise prediction model would not be valid in this range without the corrections above.

U&A 1025 states: "*The Secretary of State will require the nominated undertaker, in making predictions of noise and vibration in all reasonably foreseeable circumstances ... to include ... prediction model uncertainty*".

Both of these obligations are repeated in PFN 14. Any noise demonstration report which predicts $L_{Amax}$ in the far field range below 71dB must either: (a) adjust the predictions to take account of this evidenced error; or (b) include a section on prediction model uncertainty which clearly articulates the limitations and inaccuracies in the noise model in the far field range and quantifies the effects on all affected receptors.

The HS2 noise calculations and model limitations and inaccuracies described in the four sections of this report are all reasonably addressable and should be taken into account by the undertakers during the design and construction stages of the railway. The subsequently adjusted noise predictions should be included in the calculations in Noise Demonstration Reports and provided to Planning Authorities scrutinising these reports with full model limitations, uncertainties and errors clearly articulated.

## Appendix A – Table of Extracted Data Points

This is the table of data points extracted from the graph in the Environmental Statement.

| Calculated | Measured |
|---|---|
| 61 | 61.3 |
| 61.4 | 67.5 |
| 61.7 | 62.9 |
| 62.5 | 65.9 |
| 62.5 | 69.5 |
| 62.9 | 68.1 |
| 62.9 | 69.7 |
| 63.4 | 62.3 |
| 63.3 | 66.2 |
| 63.3 | 68.1 |
| 63.4 | 69.7 |
| 64.4 | 67 |
| 64.5 | 63.5 |
| 64.5 | 69.6 |
| 64.6 | 67.5 |
| 65.1 | 68.2 |
| 65.4 | 62.2 |
| 65.7 | 64 |
| 65.7 | 66 |
| 65.8 | 72.6 |
| 66 | 64.5 |
| 66.4 | 65 |
| 67.2 | 62.2 |
| 67.2 | 70 |
| 67.4 | 68.4 |
| 67.5 | 69.5 |
| 67.8 | 68.1 |
| 68.2 | 68 |
| 68.6 | 72.9 |
| 68.6 | 71 |
| 68.8 | 68.8 |
| 68.9 | 72.1 |
| 69 | 67.3 |
| 69.4 | 69.4 |
| 69 | 73.8 |
| 69.3 | 68.9 |
| 69.4 | 74.1 |
| 69.4 | 77.5 |
| 69.6 | 68.9 |
| 69.7 | 78.2 |
| 69.7 | 72.5 |
| 70 | 74.2 |
| 70.2 | 76.7 |
| 70.2 | 78.5 |
| 70.7 | 69.5 |
| 70.7 | 64.5 |
| 70.7 | 65.2 |
| 70.8 | 71.7 |

## Appendix B - Assumptions

For the purposes of this document it is assumed that the noise indicators used by HS2 are the same, or directly equivalent, to the indicators defined and commonly used by the WHO and END.

The HS2 noise indicators and assumed equivalent common noise indicator:

| HS2 noise indicator | Used common noise indicator |
|---|---|
| $L_{pAmax}$ | $L_{Amax}$ |
| $L_{pAeq}$ | $L_{Aeq}$ |